A New Force Balanced Accelerometer Using Tunneling Tip Position Sensing

Paul M. Zavracky, Frank Hartley, Ned Sherman and Keith Warner

Subject Area (7. Mechanical Sensors)

Abstract

In this paper, we report the initial development of a single axis bulk micromachined accelerometer. The expected sensitivity range is from ten microg foil scale with a resolution of better than one microg. The device is built from four micromachined silicon wafers of which three are distinct. The proof mass assembly is made with two identical wafers and the proof mass itself is one centimeter square by one millimeter thick and weighs approximately 0.2 grams. The completed device is about one and one half millimeters square by two millimeters.

The device employs an electron tunneling Up as a position detector in a force feedback control system (Figure 1). Control electrodes are placed above and below the proof mass and act as electrostatic force plates. Using the force plates. the position of the proof mass relative to the tunneling tip can be controlled.

Introduction

In its simplest form, conventional accelerometer consists of a proof mass, a spring and a position detector. Under steady state conditions, the proof mass experiencing a constant acceleration will move from its unperturbed position to a new position determined by the balance between its mass times the acceleration and the restoring force of the spring. Using a simple mechanical *spring, the* acceleration will be directly proportional to the distance traversed by the proof mass from its equilibrium position.

In a force feedback approach. the position of the proof *mass* is held constant. This is accomplished by feeding back position information to the control electrodes. In this work, we are exploring the application of electron tunneling tips as position sensors. The resolution of accelerometers is directly proportional to the position detection capability and the spring constant. Our approach to ultrahigh resolution devices is to incorporated a weak spring with a sensitive position detector. Tunneling tips have been used in sensors with reported resolution as low as hundredths of an Angstrom [1].

Key elements of our design include the placement of the tip such that the spacing between the neutral position of the proof mass and the top of the tip is zero. This has two beneficial effects, It reduces sensitivity to off-axis acceleration by eliminating the torque. In this design. the springs are composed of beam sections. when the proof mass is not centered the beams rue deflected. Lateral acceleration of the proof mass resolves into a normal and axial load on the springs. The normal component deflects the beam further. A second unique feature is the combined use of x and dc electrostatic fields to reach near zero effective spring constant during operation.

Fabrication Sequence

The finished device is constructed from four wafers, with the proof mass being assembled using two identical wafers. Each starts with double tided alignment. Next each is back etch in KOH to define the proof mass and separation channel. At the same time, vias are etched to permit wire bonding through the assembled structure. Chrome gold metallization provides an inert surface and electrical contacts to the surface of the proof mass. Additional electrical leads are used so align and *route electrical* connections *through the structure.* Two proof mass wafers are bonded together. This process is performed under vacuum using eutectic alloys. At this point. the proof mass is held to the surrounding silicon frame via 25 micron silicon diaphragms. *The* springs on one side of the device are patterned and etched anisotropically in an NF3 plasma.

The cover wafer is deep etched in a manner similar to the proof masses to define the separation channel. Each wafer contains a grounded bond ring that surrounds the central groove and is electrically isolated from the other electrical feature such as the force plate. The cover wafer contains a single force plate recessed in a groove in the center of the die, When completed, the cover plate is bonded to the assembled proof mass such that the side of the proof mass wafer with the springs is the side that is bonded. This permits the anisotropic etching of the springs on the exposed side of the three wafer assembly. which results in a completed proof mass and spring assembly that is free to move. As such. it must be handled carefully.

The tip wafer contains a plasma etched, oxidation sharpened gold metallized tip surrounded by four force plates. These structures are recessed in a shallow etch pit similar to that used for the cover plate. The tip is designed to protrude above the surface of the wafer at a height such that the trp reach the neutral position of the proof mass after the wafers are bonded. Electrical leads to the force plates and tips connect to contact pads at the periphery of the die. The completed tip wafer is cute.ctically bonded to the proof mass/ cover plate assembly. Since the tip wafer is placed above the proof mass during assembly, the proof mass is held away from the tip by gravity. This prevents damage to the tip during bonding. A final plasma etch process is used to separate individual die.

Results

The process has been developed and completed on all three wafer types. The tip measures about 2.5 microns in diameter at its base and is shown in Figure 2. These tips arc fabricated using a multiple step process involving plasma etching and thermal oxidation for tip sharpening. Bonded tip and proof mass dice have been mounted on test fixtures for analysis. For these dice. the springs have not yet been etched. This device allows us to evaluate the electrical behavior of the tip and force plates. in Figure 3, a plot of the tunneling tip output as a function of position is shown. Completely assembled accelerometers have not yet been tested.

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1 S.S3. Waltman and W.J. Kaiser, "Arr Electron Tunneling Sensor." Sensors and Actuators, Vol. 19, pp 201-210, (1989).

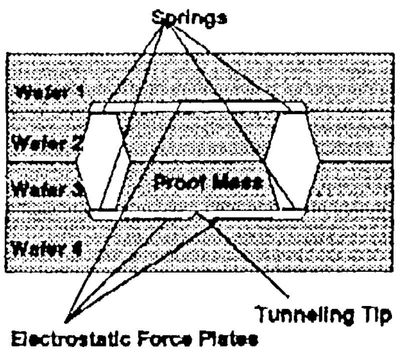

Figure 1. Schematic moss-section of the assembled accelerometer.

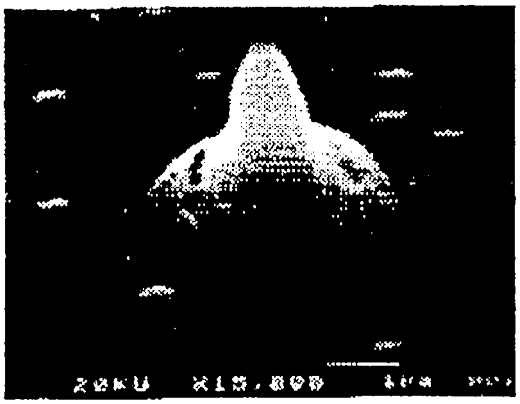

Figure 2. SEM close-up of a completed tip.

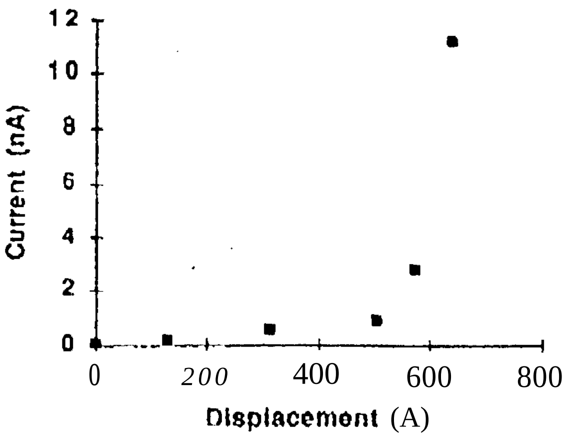

Figure 3. A Plot of the tunneling current measure.